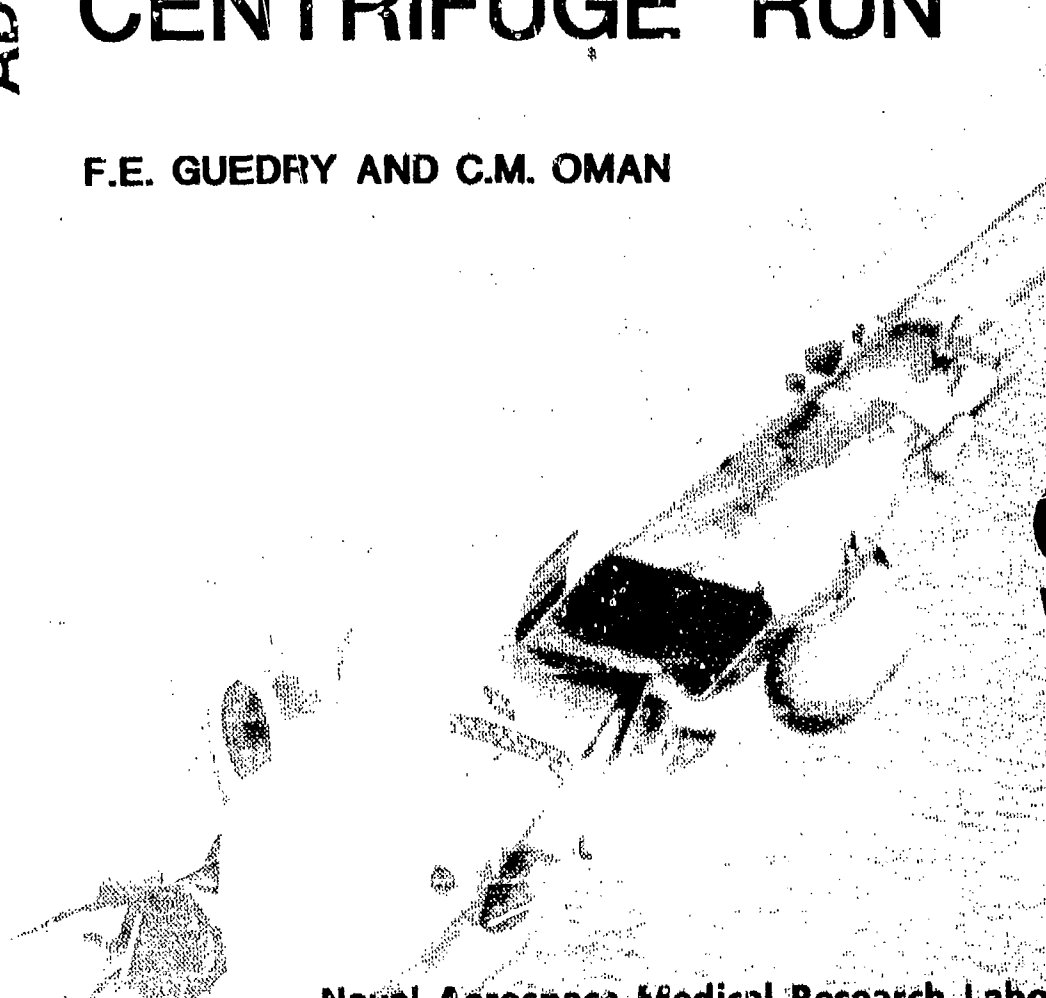


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# DTIC FILE COPY VESTIBULAR STIMULATION DURING A SIMPLE CENTRIFUGE RUN

F.E. GUEDRY AND C.M. OMAN



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13. ABSTRACT (Maximum 200 words) Vestibular stimuli throughout a simple centrifuge run are described in this report, which is the first in a report series that is part of our basic research devoted to an Office of Naval Research accelerated research initiative on vestibular transduction. Herein, we compare stimuli throughout the initial angular acceleration with stimuli during the deceleration that ends the run. We provide tables that show differing rates of change of linear and angular acceleration vectors during the acceleration and deceleration, and we discuss the research steps needed to explain disorientation abhorrence reactions and spatial orientation perceptions in centrifuge runs. In subsequent studies, we record vestibular responses during and after centrifuge runs and examine how well responses are predicted by models of vestibular transduction processes.					
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## SUMMARY PAGE

### THE PROBLEM

The Office of Naval Research, through an Accelerated Research Initiative, is sponsoring studies of vestibular transduction. One of the primary objectives of this initiative is to develop knowledge of techniques and procedures to reduce problems associated with disorientation and motion sickness. Part of our research on this initiative examines the capability of current models of the vestibular transducers and higher level models to predict sensorimotor reactions, stress reactions, and perceived spatial orientation throughout simple and complex vestibular stimuli such as those produced on centrifuge runs and aerospace operations.

### FINDINGS

Anecdotal reports and our preliminary studies indicate great differences in responses to the acceleration and deceleration of centrifuge runs. Our analysis of vestibular stimuli throughout the course of a simple prototype centrifuge run shows no corresponding obvious difference in vestibular stimuli but the rate of change of linear and angular accelerations vectors differ, and subtle changes in combinations of otolith and semicircular canal responses have been shown to control disorientation stress reactions. Ongoing studies are examining how well existing models predict vestibular responses.

### RECOMMENDATIONS

A major source of dissatisfaction by aircrew with the use of centrifuges for g-tolerance training is the disorientation abhorrence reaction and nausea produced by deceleration of the centrifuge. One of our research objectives is to understand these reactions and in the process of developing this understanding we will explore procedures that reduce these effects. We recommend that this research continue to advance basic knowledge in areas that are significant to the Navy.

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## INTRODUCTION

This report describes part of the research being conducted in our laboratory in pursuit of an accelerated research initiative on vestibular transduction sponsored by the Office of Naval Research (ONR). The ONR support of basic research in the overall Navy research program is intended to provide opportunity for researchers to select experimental conditions solely because they seem likely to advance understanding of the biological system. This adds needed balance to an overall research program in which experimental conditions are more often selected because they mimic some component of the operational environment, usually a component that seems to threaten adequate performance or well-being. The ONR philosophy has provided us with the opportunity to pursue an understanding of reports of a curious difference in reactions to acceleration and deceleration of the centrifuge. Substantial differences in the magnitude of vestibular reactions to the acceleration and deceleration have been reported anecdotally. Can we substantiate these reports, and are the reactions consistent with current models of the vestibular transducers? In these studies, we choose to alter the subject's orientation (position) relative to the developing linear acceleration components in ways not common to centrifuge operations. We select these conditions to explore how well current models of the vestibular transducers predict vestibular responses to complex combinations of linear and angular accelerations.

This report discusses vestibular responses to combinations of linear and angular accelerations produced by a simple human centrifuge run in which the subject is seated in a pendulous chair so that the head-to-seat axis (z axis) of the body maintains alignment with the resultant of the centripetal acceleration and gravity throughout the run. We describe an overview of the progression of vestibular stimuli during the run.

Subsequent reports will provide 1) an overview of the progression of perceptual and arousal reactions associated with the stimuli, 2) a description of the predicted dynamic physical response of the vestibular transducers, 3) more detailed description of perceptual reactions 4) quantitative description of the vestibulo-ocular reflex throughout the stimulus sequence and 5) model revision as necessary.

## STIMULI TO THE SEMICIRCULAR CANALS

For the purpose of this report series, a simple centrifuge run is defined as an angular velocity profile (sometimes referred to as a ramp profile) consisting of constant angular acceleration to constant angular velocity which is sustained for several minutes followed by negative constant angular acceleration to zero velocity. Figure 1 illustrates the angular velocity profile of a prototype simple centrifuge run

The initial angular acceleration (the up-ramp) of the centrifuge is of constant magnitude until steady-state angular velocity is attained, but the planes of the semicircular canals change relative to the angular acceleration vector so that the effective stimulus to the semicircular canals changes throughout the up-ramp acceleration. Similar changes occur throughout the angular deceleration (the down-ramp) to a stop. In this section, we describe

the angular acceleration stimuli as they project to the z-axis and y-axis of the head during a simple centrifuge run.

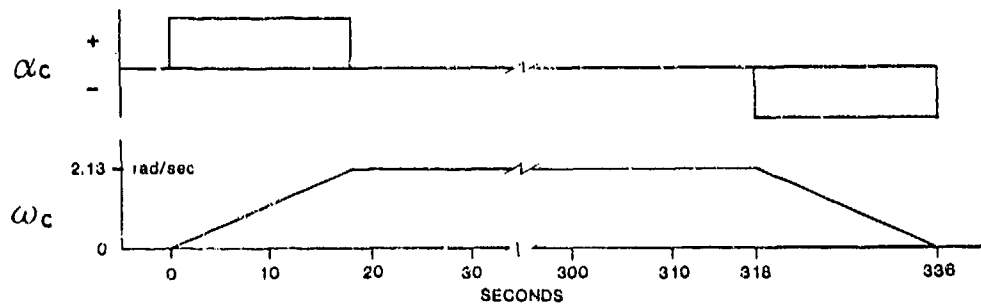


Figure 1. Profile of angular velocity and of angular acceleration during a simple centrifuge run.

Figure 2 illustrates x, y, and z axes of the head as defined previously (1,2). Positive polarity is toward the front (forward looking) for x, toward the left for y, and upward from the vertex of the head for z. For angular motions, x, y, and z are respectively roll, pitch, and yaw axes of the head. Representation of angular acceleration as vectors is advantageous for descriptive purposes. The length of the vector (arrow) represents the magnitude of the angular acceleration, the shaft of the arrow designates the axis of angular acceleration, and the arrowhead designates the direction of rotation according to the right-hand rule, illustrated in the right side of Fig. 2.

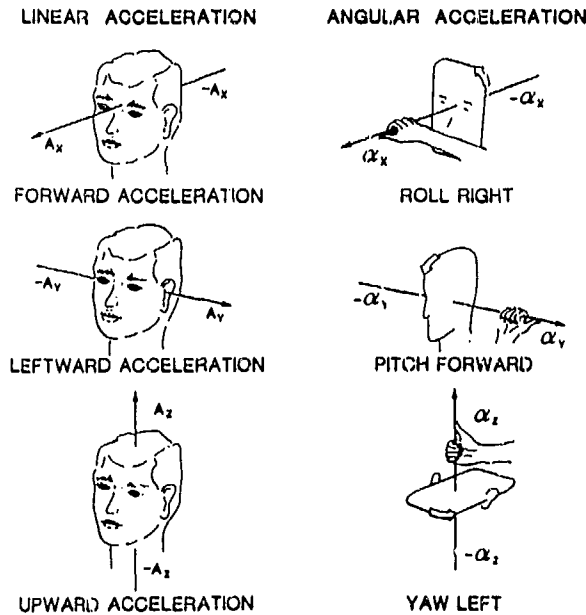


Figure 2. Polarities for describing head-referenced linear and angular acceleration vectors.

By the right hand rule, the thumb points in the direction of the arrowhead, and the curl of the fingers designate the rotation direction. For example,

the thumb points upward along the z axis in the direction of the arrowhead, and the curl of the fingers indicate a counterclockwise yaw rotation. By this rule and our head-referenced nomenclature, counterclockwise rotation is positive, roll right is positive, and pitch forward (forward tumble) is positive. Gravity is represented as a vector drawn upward pointing away from the earth's surface (see Figs. 3, 4, 5 & 6). With these conventions defined, we now describe the angular acceleration stimuli projected to axes (and planes) of the head.

As angular acceleration,  $\alpha_c$ , of the centrifuge commences in a counterclockwise direction, the centripetal acceleration (which is the product of the square of the angular velocity,  $\omega_c$ , and the radius  $r$ ) increases because  $\omega_c$  is increasing. A free-swinging chair pivoted about a tangential axis will maintain alignment with the resultant of the acceleration of gravity,  $g$ , and the centripetal acceleration. Therefore, the z axis of a subject seated upright in the chair and facing in forward tangential direction will tilt (roll left) relative to gravity according to:

$$\phi_x = \tan^{-1} \left[ \frac{\omega_c^2 r}{g} \right]$$

where  $\phi_x$  is the angle in the roll plane (y-z plane) of the head measured from the z axis of the head to the g-vector. Substituting  $\alpha_c t$  for  $\omega_c$  yields

$$\phi_x = \tan^{-1} \left[ \frac{(\alpha_c t)^2 r}{g} \right] \quad (1)$$

where  $t$  is time elapsed following onset of angular acceleration.

The angular position of the subject relative to gravity at some time,  $t$ , during  $\alpha_c$  is illustrated in Fig. 3. Because the planes of the semicircular canals change relative to the axis of  $\alpha_c$ , the influence of  $\alpha_c$  on the canals changes throughout the duration of  $\alpha_c$ .

A true angular accelerometer will respond the same irrespective of its distance from the center of a centrifuge as the centrifuge undergoes angular acceleration. An idealized semicircular canal would give the same response during angular acceleration of a centrifuge irrespective of its radial distance from center.

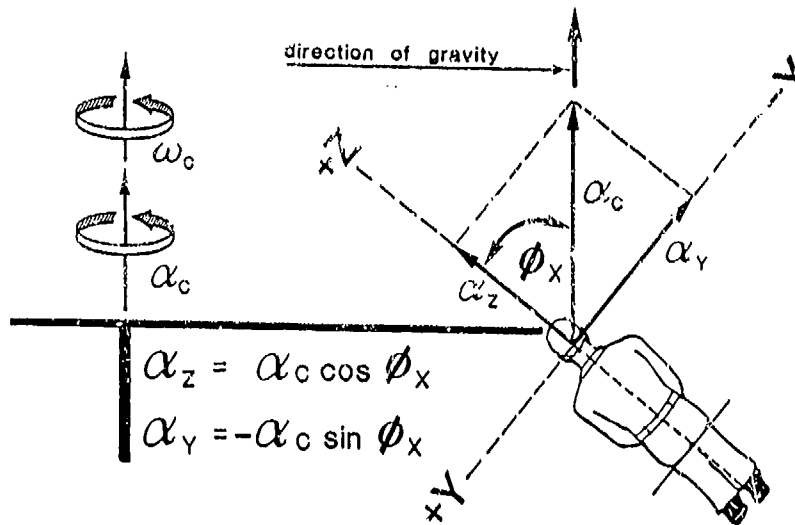


Figure 3. Angular acceleration components acting on the z and y axes of the head from the up-ramp angular acceleration as the head changes position relative to the centrifuge.

The component of  $\alpha_c$  imparted to the z axis of the head is:

$$\alpha_z = \alpha_c \cos \phi_x \quad (2)$$

and the component of  $\alpha_c$  projected to the y axis of the head is:

$$\alpha_y = -\alpha_c \sin \phi_x \quad (3)$$

The semicircular canals are also stimulated during  $\alpha_c$  by additional angular acceleration from cross-coupled effects of two angular velocities, one being the angular velocity of the centrifuge,  $\omega_c$ , and the other being the angular velocity of the swinging chair, which is also the angular velocity of the head in its roll plane, designated  $\omega_x$ . The additional angular acceleration vector, sometimes called Coriolis angular acceleration, has a magnitude equal to  $\omega_x \omega_c$ , and it lies in the plane of rotation of the centrifuge (1,2). Its direction is such that it would turn the arrowhead end of the  $\omega_x$  vector in the direction of turn of  $\omega_c$ . In our prototype run, the centrifuge is rotating counterclockwise so that  $\omega_c$  is positive.

The rate of change of  $\phi_x$  as the subject rolls left during the up-ramp angular acceleration is  $\dot{\phi}_x$ , which is the angular velocity about the x axis:

$$\dot{\phi}_x = \omega_x = - \frac{2g(\alpha^2 t) r}{[g^2 + (\alpha t)^4 r^2]} \quad (4)$$

Roll left is negative by our man-referenced nomenclature, so  $\omega_x$  is negative, and it points in the negative direction of the x axis.

The directions of  $\omega_c$ ,  $\omega_x$  and  $\omega_x \omega_c$  vectors for our prototype run during  $\alpha_c$  are illustrated in Fig. 4. They are orthogonal to one another. The  $\omega_x \omega_c$  vector projects laterally below the subject's right ear. The component of this vector acting on the subject's y axis is:

$$\alpha_y \text{ cor} = \omega_x \omega_c \cos \phi_x$$

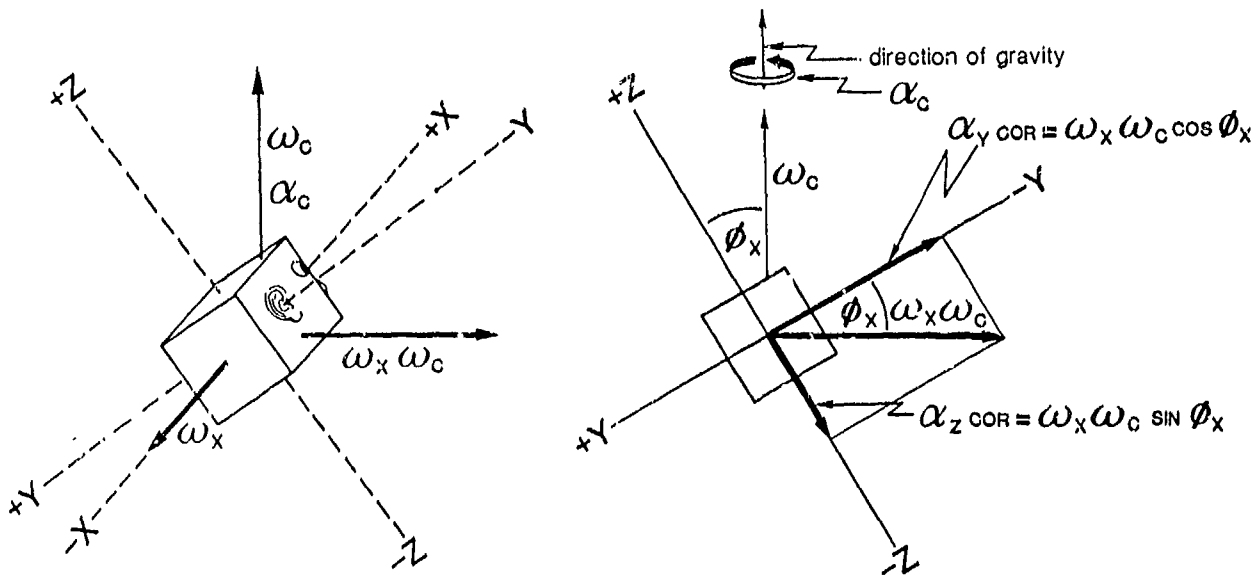


Figure 4. Angular acceleration components acting on the z and y axes of head from the cross coupling of angular velocity of the centrifuge and angular velocity about the x-axis during the up-ramp.

Because  $\omega_x$  is negative,  $\alpha_y \text{ cor}$  is negative, and it points in the -y direction. The component of  $\omega_x \omega_c$  acting on the subject's z axis is:

$$\alpha_z \text{ cor} = \omega_x \omega_c \sin \phi_x$$

This component is also negative because  $\omega_x$  is negative.

In summary, during angular acceleration of the centrifuge, the total angular acceleration referred to the z axis is the sum of two vectors,  $\alpha_z$  and  $\alpha_z \text{ cor}$ :

$$\Sigma \alpha_z = \alpha_c \cos \phi_x + \omega_x \omega_c \sin \phi_x \quad (5)$$

and the total angular acceleration referred to the y axis is the sum of  $\alpha_y$  and  $\alpha_y \text{ cor}$ :

$$\Sigma \alpha_y = -\alpha_c \sin \phi_x + \omega_x \omega_c \cos \phi_x \quad (6)$$

#### Stimuli to the Semicircular Canals During the Down-ramp

In stopping the centrifuge, the angular acceleration is negative in sign, but rotation of the centrifuge remains counterclockwise until stop occurs so that  $\omega_c$  remains positive. Figure 5a illustrates the directions of the angular velocity and angular acceleration vectors of the centrifuge during the down ramp.

Because of the existing angular velocity,  $\omega_o$ , when the deceleration commences, the centripetal acceleration during deceleration is  $(\omega_o - \alpha_c t)^2 r$  and

$$\phi_x = \tan^{-1} \left[ \frac{(\omega_o - \alpha_c t)^2 r}{g} \right] \quad (7)$$

the rate of change of  $\phi_x$  is  $\omega_x$ , which is:

$$\dot{\phi}_x = \omega_x = \frac{2g \alpha_c (\omega_o - \alpha_c t) r}{[g^2 + (\omega_o - \alpha_c t)^2 r^2]} \quad (8)$$

Because the z axis is returning from roll left toward upright,  $\omega_x$  is a roll-right velocity, which is positive. Figure 5b illustrates the projection of  $\omega_x \omega_c$  onto the y and z axes of the head during the down-ramp.

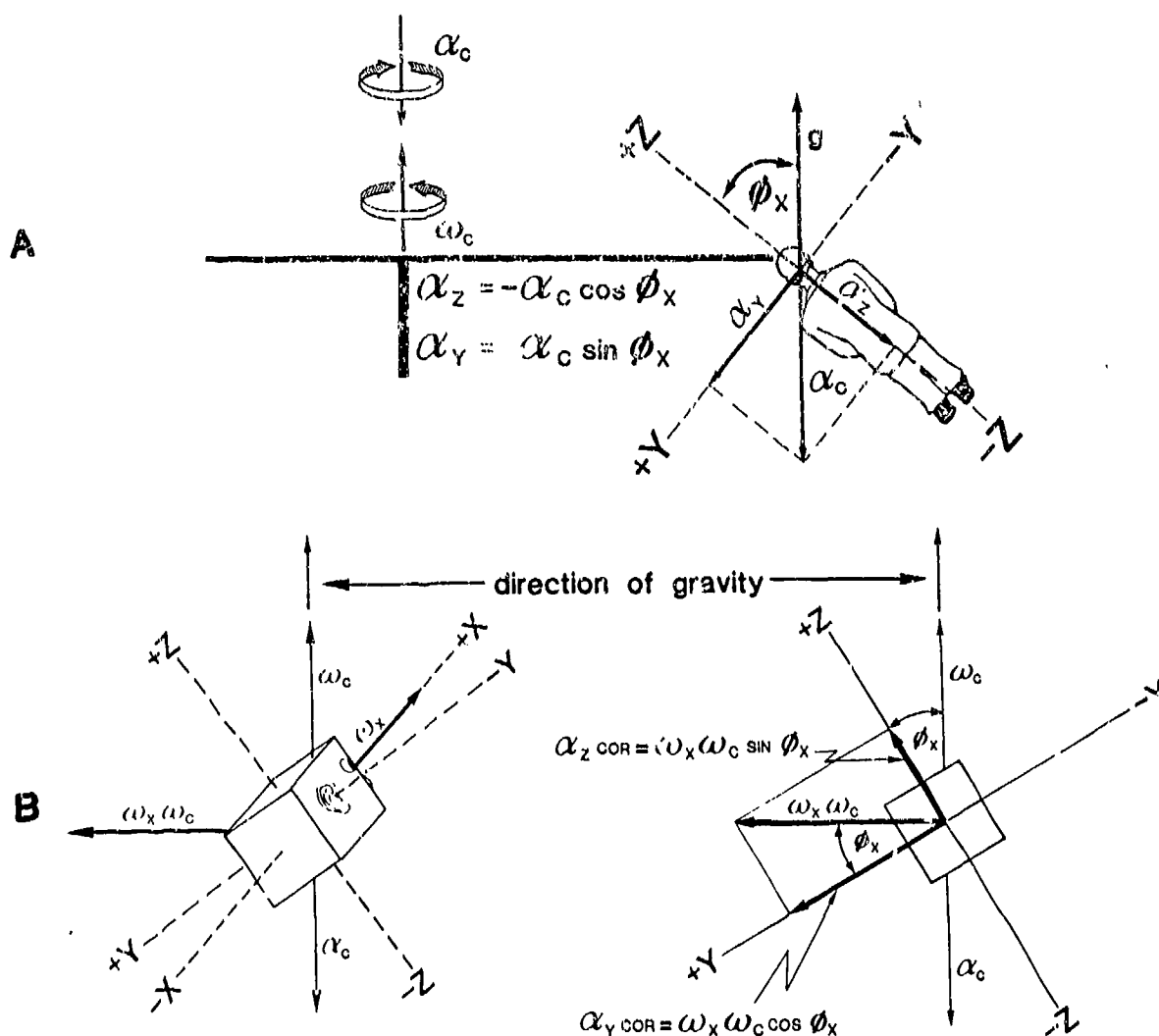


Figure 5. Angular acceleration components acting on the  $z$  and  $y$  axes of the head from the down-ramp angular acceleration (Fig. 5a) and from the cross-coupling of centrifuge angular velocity and angular velocity about the  $x$ -axis (Fig. 5b) during the down-ramp angular acceleration.

By the same rationale and conventions used in arriving at equations 5 & 6 for the up-ramp angular acceleration, the total angular acceleration component referred to the  $z$ -axis from  $-\alpha_c$  and from  $\omega_x \omega_c$  is:

$$\Sigma \alpha_z = -\alpha_c \cos \phi_x + \omega_x \omega_c \sin \phi_x \quad (9)$$

and referred to the  $y$ -axis:

$$\Sigma \alpha_y = \alpha_c \sin \phi_x + \omega_x \omega_c \cos \phi_x \quad (10)$$

For illustrative purposes, we select the following stimulus values:  
 $\alpha_0 = .118 \text{ rad/s}^2$ ,  $\alpha_0$  duration = 18 s, radius = 20 ft. With these values,  
 $\omega_0 \text{ max} = 2.13 \text{ rad/s}$ . By using the selected stimulus values and by substituting appropriately into equations 5 and 6, we can calculate the magnitude and direction of the resultant angular acceleration vector in the y-z plane of the head throughout the up-ramp acceleration. Similarly, with equations 9 and 10, the magnitude and direction of the resultant angular acceleration in the y-z plane of the head can be determined throughout the down-ramp acceleration. Figure 6 shows the angular acceleration vector in the y-z plane at 1, 6, 12 and 18 s into the period of the up-ramp acceleration (Fig. 6a) and into the period of the down-ramp acceleration (Fig. 6b).

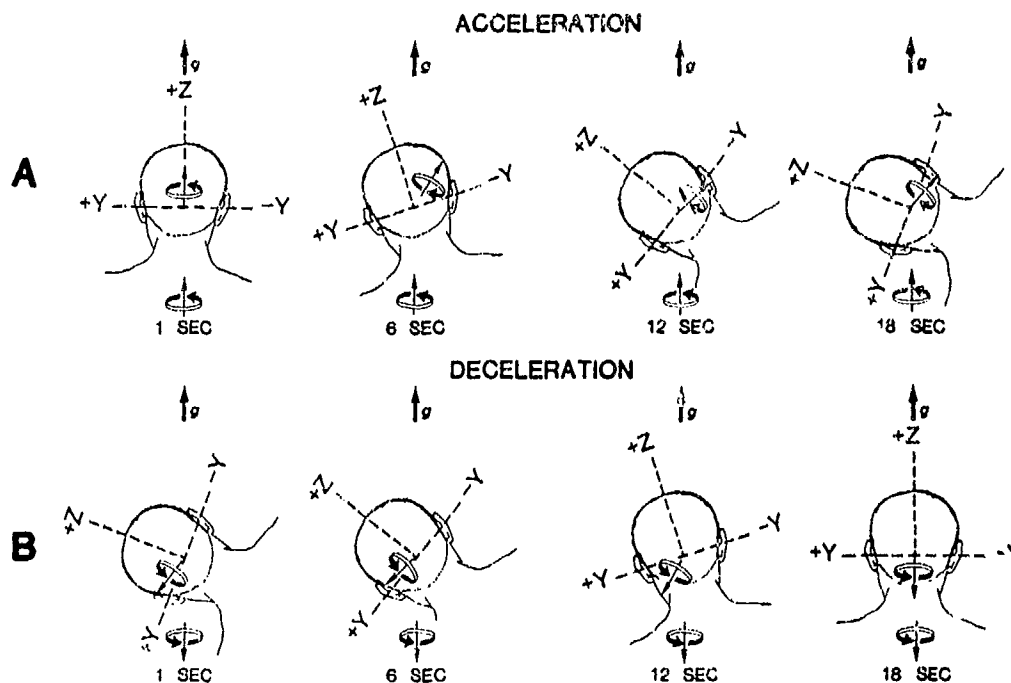


Figure 6. Direction of the resultant angular acceleration vector relative to the head at selected points during the up-ramp (Fig. 6a) and during the down-ramp (Fig. 6b).

#### ANGULAR ACCELERATION ABOUT THE X AXIS

Until now, we have ignored angular acceleration about the x axis,  $\alpha_x$ . Except for runs involving high-onset rates to high G levels,  $\alpha_x$  will be small, and because it reverses direction, its accumulative vestibular effects will be even less. With our selected stimulus values, a resultant force of 3.0 Gz occurs when constant velocity is attained at 18 s and a  $\phi_x$  offset from gravity of 70.4 deg is attained. The subject has rolled through 70.4 deg in 18 s. During the down-ramp acceleration, the subject rolls from 70.4 deg to upright. Thus, the subject experiences  $\alpha_x$  profiles during the up-ramp and down-ramp accelerations approximately as illustrated in Figs. 7a and 7b.

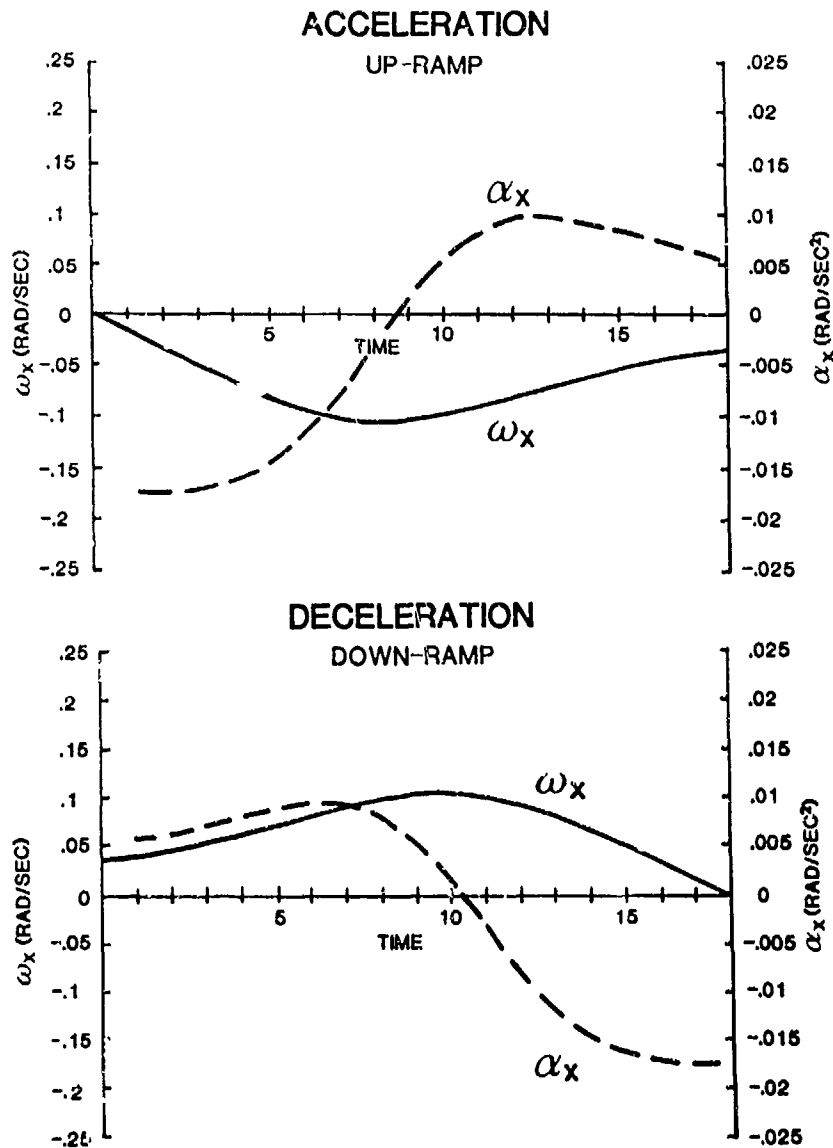


Figure 7. Angular acceleration and angular velocity about the x axis calculated for the particular conditions of our prototype run. Due to inertia, our centrifuge produces a gradual acceleration step; therefore, the onset of  $\alpha_x$  is more gradual than depicted here.

The magnitude of  $\alpha_x$  at some points in its time course is slightly greater than the magnitude of concomitant  $\alpha_y$  or  $\alpha_z$  components but it is never large relative to both  $\alpha_y$  and  $\alpha_z$ . Thus, in our stimulus profile,  $\alpha_x$  is not at any point in time a predominant acceleration vector and the accumulative  $\omega_x$  (see Table 1 below) is never large.

The effect of  $\alpha_x$  would be to gradually deflect the total resultant angular acceleration vector slightly out of the y-z plane, first in one direction and then in opposite direction, with only slight changes in magnitude of the resultant vector.

## STIMULI TO THE OTOLITH SYSTEM

Figure 8 illustrates the position of the subject relative to gravity and to the resultant force during the run. At  $t = 18$  s, the subject is in roll-left position relative to gravity of  $\phi_x = -70$  deg, however, the resultant vector of  $\omega_c^2 r$  and  $g$  has remained aligned with the  $z$  axis so that the otolith system has not experienced a lateral shear force. The sustained  $z$ -axis alignment of the resultant force generates a sustained zero-roll otolith stimulus throughout the stimulus profile.

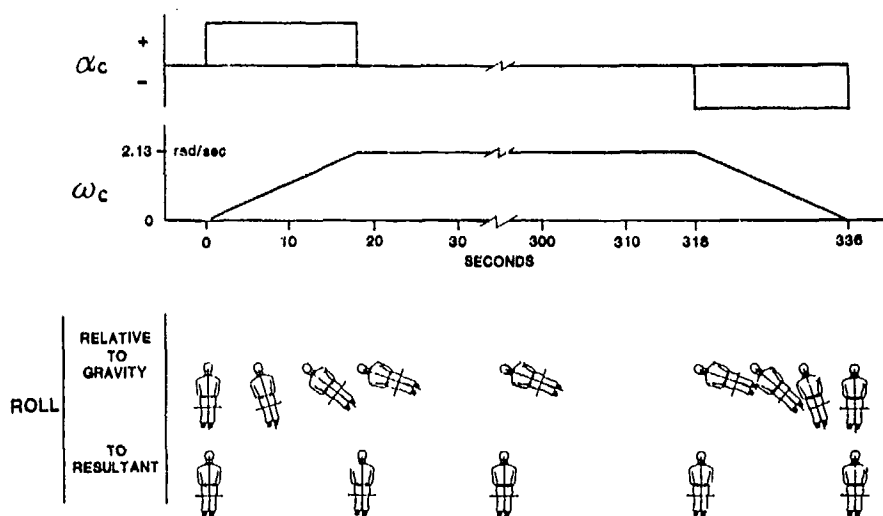


Figure 8. Roll position of the head and body relative to gravity and relative to the resultant linear acceleration vector of the centripetal and gravity vectors.

During  $\alpha_c$ , a tangential linear acceleration,  $\alpha_c r$ , is also present. This linear acceleration component is present during the "up-ramp." It is zero throughout the constant velocity segment, and it occurs in reversed sign during the down ramp. Tangential acceleration with the subject facing in forward tangential heading is aligned with the subject's  $x$  axis (Fig. 9). Its magnitude in our run is  $2.36 \text{ ft/s}^2$ . The resultant vector from tangential acceleration and gravity is tilted forward relative to the  $z$  axis  $4.2$  deg ( $\phi_y = 4.2$  deg) at the onset of the up-ramp, but it decreases to  $1.4$  deg as  $3G$  is approached because the tangential vector is resolved with  $3$  instead of  $1G$ .

If  $\alpha_c r$  were large, the subject would be in pitch-up orientation relative to the resultant as shown in the inset of Fig. 9. Because our  $\alpha_c r$  is very small, little if any pitch-up perception would be expected from the  $\phi_y$  shift in the direction of the resultant linear acceleration relative to the head and because of a "lag effect" (2, p. 106f), no pitch-up perception would be expected in our run.

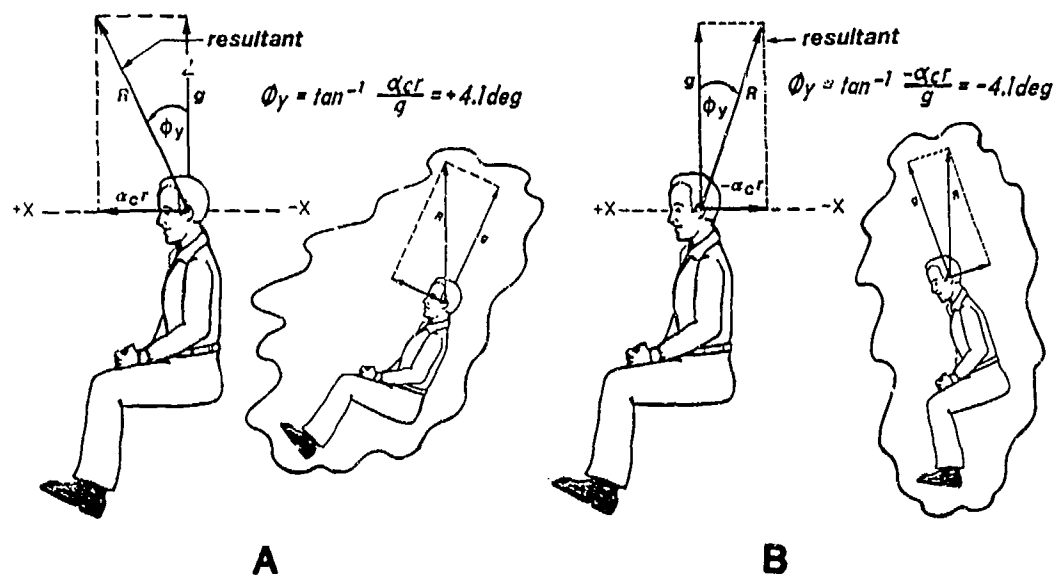


Figure 9. Tangential acceleration on the x-axis of the head and possible pitch-perception effects (inset) from changes in direction of the resultant of the x axis tangential acceleration and z axis linear acceleration during up-ramp Fig. 7a and down-ramp Fig. 7b. Pitch effects depicted are unrealistically large for our low magnitude tangential acceleration.

During the down-ramp, the resultant of the tangential deceleration and gravity is shifted (rotated) backward relative to the z axis as shown in Fig 9B. The tangential acceleration is  $2.36 \text{ ft/s}^2$ . At the beginning of the down ramp,  $\phi_y = 1.4 \text{ deg}$ , but it increases to  $4.2 \text{ deg}$  as the G-level diminishes and then goes to zero at stop. It presents very little forward pitch (nose-down) stimulus in our profile and as during the up-ramp, little expected effect on pitch perception.

In summary, although the subject rolls left during  $\alpha_c$ , the resultant of the centripetal acceleration and gravity remains aligned with the subject's z axis. The resultant vector of the tangential acceleration and gravity shifts slightly (4 deg) to produce a weak pitch-up stimulus during acceleration and a weak pitch-down stimulus during deceleration. Otolith stimuli from changes in direction of linear acceleration relative to the head are almost negligible. Hyper-G effects on otolith shear, to be discussed in a later report, would have perceptual consequences (2,3) if the head were positioned so that the mean plane of the utricular otolith was not normal to the 3G vector.

#### OVERVIEW OF VESTIBULAR STIMULI DURING RUN

Table 1 presents yaw, pitch, and roll angular accelerations experienced at the z, y and x axes of the head at different times during the up-ramp

including times that correspond to those depicted in Fig. 6. Because the semicircular canal response tends to follow the velocity derivative of the stimulus, the accumulative angular velocity on each axis (x, y, z) is also shown in Table 1. Table 2 presents comparable information for the down ramp.

TABLE 1. Angular Acceleration, Velocity and Displacement, and Linear Acceleration During Up-ramp Acceleration.

Time (s)	Angular acceleration (deg/s <sup>2</sup> )			Accumulative angular velocity (deg/s)			Angular displacement of z axis from gravity (deg)		Angular displacement of z axis from resultant (deg)		Linear acceleration (g-units)	
	Yaw	Pitch	Roll	Yaw	Pitch	Roll	Pitch	Roll	Pitch	Roll	x axis	z axis
1	6.8	-0.2	-1.0	6.8	-0.2	-1.0	0	-0.5	-4.2	0	0.07	1.00
3	6.7	-1.6	-.9	20.2	-2.5	-2.9	0	-4.5	-4.2	0	0.07	1.00
6	5.3	-5.7	-0.7	38.0	-15.1	-5.5	0	-17.4	-3.9	0	0.07	1.05
9	1.9	-9.1	0.1	47.3	-39.7	-5.7	0	-35.1	-3.4	0	0.07	1.21
12	-0.9	-9.4	0.6	46.9	-68.2	-4.5	0	-51.4	-2.6	0	0.07	1.60
15	-1.8	-8.5	0.5	42.0	-94.7	-2.8	0	-62.9	-1.9	0	0.07	2.14
18*	-6.7	-7.8	0.3	36.5	-118.8	-1.9	0	-70.4	-1.4	0	0.07	2.99

Signs indicate direction of yaw, pitch, and roll accelerations, velocities, and displacements.

\*18 s = 17.99 s

TABLE 2. Angular Acceleration, Velocity and Displacement, and Linear Acceleration During Down-ramp Acceleration.

Time (s)	Angular acceleration (deg/s <sup>2</sup> )			Accumulative angular velocity (deg/s)			Angular displacement of z axis from gravity (deg)		Angular displacement of z axis from resultant (deg)		Linear acceleration (g-units)	
	Yaw	Pitch	Roll	Yaw	Pitch	Roll	Pitch	Roll	Pitch	Roll	x axis	z axis
0	0	0	0	0	0	0	0	-70.4	0	0	0	2.99
1	1.8	8.0	.3	1.8	8.0	2.3	0	-68.3	1.5	0	-.07	2.70
3	1.7	8.5	.4	5.4	24.6	2.9	0	-62.9	1.9	0	-.07	2.14
6	0.9	9.4	.6	9.4	52.2	4.6	0	-51.4	2.6	0	-.07	1.60
9	-1.9	9.1	.3	6.2	79.3	5.7	0	-35.1	3.4	0	-.07	1.21
12	-5.3	5.7	-.6	-5.6	101.6	5.4	0	-17.4	4.0	0	-.07	1.00
15	-6.6	1.6	-.9	-25.6	103.1	2.9	0	-4.5	4.1	0	-.07	1.00
18*	-6.7	0	-1.0	-45.0	111.1	0	0	0	4.2	0	-.07	1.00

\*t = 17.99 s

The accumulative angular velocity columns in Tables 1 and 2 show that the main semicircular canal stimulation in both the up-ramp and down-ramp is y-axis (pitch-axis) stimulation with the total effect being about equivalent for the up-ramp and down-ramp. Very little effect remains for the roll axis as the up-ramp and down-ramp terminate owing to the reversal of the sign of  $\alpha_x$  during its course. Because of sign reversal and roughly equivalent stimulation in either direction, even high-onset rates would yield little residual effect on the x axis at the end of the ramp.

An interesting aspect of the stimulus characteristic is the fact that at the beginning of the down ramp, yaw-axis angular acceleration is positive even though  $\alpha_y$  is negative. This is due to the cross-coupled ( $\omega_x \omega_y$ ) effect, which is fairly large when the horizontal canals are 70 deg from the plane of rotation while the direct effect of  $\alpha_y$  on the horizontal canals is relatively weak in that position.

Tables 1 and 2 also provide a look at the rate of change of acceleration vectors. Noteworthy is the fact that in the first 6 s of the up-ramp,  $G_z$  increases only 0.05 g units, whereas in the first 6 s of the down ramp,  $G_z$  decreases by about 1.4 g units. The rate of change of  $G_z$  is much higher during the early part of the down-ramp. A similar disparity is present for pitch axis accumulative angular velocity. In the first 6 s of the up-ramp, 15 deg/s pitch up velocity is accumulated whereas in the first 6 s of the down ramp, 52 deg/s pitch down velocity is accumulated. Thus, although the total accumulative effect as the up and down-ramps terminate at 18 s are about equal, different rates of change of angular stimuli have occurred, and these have been accompanied by different rates of change of linear acceleration stimuli.

For the greater part of both the up-ramp and the down ramp, semicircular canal stimuli and otolith stimuli are disparate. The semicircular canals signal rotation of the head about an axis that is continually changing orientation relative to the head while the otolith system indicates little or no change in orientation of the head relative to the resultant force. Another potentially significant difference between up-ramp and down-ramp stimulation is the magnitude of the linear acceleration vector when the accumulative velocity stimulation is greatest. At the end of the up-ramp, semicircular canal stimulation is maximum as otolith stimulation becomes maximum. At the end of the down-ramp, semicircular canal stimulation is maximum when otolith stimulation is reduced to 1G--a minimum for the run. In papers that follow we will describe how these interacting messages influence the dynamics of spatial orientation, arousal reactions and the vestibulo-ocular reflex.

The subtlety of what contributes an element of abhorrence to experiencing particular forms of vestibular stimulation has been previously indicated (4). When the head is centered on a rotating platform, tilting the head relative to the plane of rotation produces cross-coupled semi-circular canal stimulation known to be very disturbing and nauseogenic. The same cross-coupled stimulus is not at all disturbing when the head movement is executed quickly during or immediately after the up-ramp angular acceleration. The absence of disturbance was explained (4) by the fact that the total resultant angular acceleration vector (from the accumulative effects of the angular acceleration on the

semicircular canals before the head tilt resolved vectorially with the immediate cross-coupled effects produced by the head tilt) remains aligned with gravity. Thus, the semicircular canals signal rotation about an axis that is aligned with gravity thereby avoiding the canal-otolith conflict that occurs when the head movement is executed after the semicircular canal response to the up-ramp acceleration has subsided. The degree to which semicircular canal effects are accumulated during our up-ramp acceleration to interact with the accumulating cross-coupled effects to control the sensed angular vector alignment with gravity is a matter of transduction dynamics to be dealt with in subsequent reports. However, even if sensed angular vector were approximately maintained in alignment with gravity during the up-ramp, vestibular conflict would not be avoided in our centrifuge run because the total resultant linear acceleration vector is not aligned with gravity (see Fig. 8). Thus, in both the up-ramp and down-ramp acceleration of the centrifuge run, strong canal-otolith conflict occurs, and we cannot use this earlier (4) explanation to account for the major up-ramp/down-ramp differences in abhorrence reactions that have been reported anecdotally and that we are observing in our on-going studies.

We introduce the expression *disorientation abhorrence reaction* here to focus attention on the immediate dislike, distress, and even fear that some subjects experience during this form of vestibular stimulation and to clearly distinguish this aspect of the immediate experience from the nausea that may or may not occur secondarily. From our preliminary observations, vestibular abhorrence reactions are distinctively different during the up-ramp and down-ramp. To understand abhorrence reactions and spatial orientation perceptions at any given point in an acceleration profile, we need to know the accumulative effects of preceding stimulation on the state of the vestibular transducers as new (or continuing) accelerative stimuli occur. This cannot be accomplished without knowledge of the dynamics of the transduction process. The sensory input of an immediate vestibular stimulus is absolutely dependent on the state of motion and state of deformation of the sensory transducer when the immediate stimulus is introduced. To specify this input, we must have good models of vestibular transducer mechanics and of transducer processes. We also know that we must go beyond vestibular transduction inputs to understand (which means predict) spatial orientation and spatial disorientation abhorrence reactions. For example, motion of the entire visual scene introduces brainstem activity resembling vestibular inputs (5) that can convert a disorientation abhorrence reaction into a benign essentially accurate motion perception (6). We anticipate that the understanding of events in a simple centrifuge run will prove to be an interesting, productive avenue of basic research with practical end products.

#### RECOMMENDATIONS

A major source of dissatisfaction by aircrew with the use of centrifuges for g-tolerance training is the disorientation abhorrence reaction and nausea produced by deceleration of the centrifuge. One of our research objectives is to understand these reactions and in the process of developing this understanding we will explore procedures that reduce these effects. We recommend that this research continue to advance basic knowledge in areas that are significant to the Navy.

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Other Related NAMRL Publications

None are applicable.